PCTR MEASUREMENT OF k_{∞}
FOR URANIUM THORIA SUPERCELL

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PCTR MEASUREMENT OF k_{∞} FOR URANIUM THORIA SUPERCELL

I. INTRODUCTION AND SUMMARY

Experimental measurements have been made on a test lattice of separable tubes of fuel and target material in a graphite moderated lattice in the Physical Constants Test Reactor (PCTR). Measurements were made of the infinite medium neutron multiplication factor on a supercell defined here as separate graphite moderated lattice cells consisting of three uranium fuel cells and one thoria target cell. The measured parameters include data for two distinct fuel types in lattices with and without coolant consisting of 1.25 wt% enriched uranium fuel and thoria target at 77% theoretical density in separate process tubes.

Determinations of k_{∞} were made with the coolant channels wet and dry, and with two differing fuel sizes to obtain an estimate of the change in reactivity due to water loss as a function of coolant and fuel geometry. The experimental results are listed in Table I.

TABLE I

Lattice Parameters Determined from PCTR Measurements
1.25% Enriched Fuel and Thoria Target (77% Theoretical Density)

<u>Fuel Size</u>	<u>Lattice Condition</u>	<u>Thermal Util.(f)</u> <u>(Air atmosphere)</u>	<u>k_∞ (Air</u> <u>atmos.)</u>	<u>k_∞ (Vacuum</u> <u>atmosphere)</u>
1.449" O.D.	Dry Target, Dry Fuel	0.79526 ± .005	1.0857 ± .0057	1.0891 ± .0057
1.449" O.D.	Wet Target, Wet Fuel	0.76324 ± .005	1.0644 ± .0056	1.0681 ± .0056
1.392" O.D.	Dry Target, Dry Fuel	0.78009 ± .006	1.0886 ± .008	1.0920 ± .008
1.392" O.D.	Wet Target, Wet Fuel	0.74380 ± .006	1.0486 ± .008	1.0523 ± .008

Reactivity change due to water loss:

$$\frac{\Delta k_{\infty} \text{ (Wet } \rightarrow \text{ Dry)}}{k_{\infty} \text{ Wet}} = 1.97\% \frac{\Delta k}{k} \text{ for 1.449" O.D. fuel}$$

(vacuum atmosphere)

$$= 3.77\% \frac{\Delta k}{k} \text{ for 1.392" O.D. fuel}$$

(vacuum atmosphere)

The decrease in fuel size reduces the potential reactivity of the system; however, the potential water loss is increased significantly because the coolant volume is enhanced by the smaller fuel. The coolant is more of a neutron absorber and shield than it is a moderator in the already over-moderated lattice.

Several perturbation measurements were taken to determine the reactivity change due to limited water loss in the target and fuel. These results indicate that water loss in the target will also increase reactivity but

that this effect is not as large as the increase in reactivity due to water loss in the fuel. Absolute neutron multiplication factors were not derived from this data because the mass of copper which is required to achieve unit multiplication in the test lattice is sensitive to the mismatch of the neutron spectrum incident on the cell. Results of the perturbation measurements are listed in Table II in terms of the measured mass of copper (M_o) necessary to achieve unit multiplication in the perturbed cell. All measurements were made in the matched spectrum of the wet lattice with 1.449" O.D. fuel geometry.

TABLE II

Relative Mass of Copper Required to Compensate for Coolant Perturbations

<u>Cell Condition</u>	<u>M_o (Relative)</u>	<u>$k_{\infty}-1$</u>
Wet Target, Wet Fuel	1.00	0.0644
Dry Target, Wet Fuel	1.07	- - -
Wet Target, Dry Fuel	1.56	- - -
Dry Target, Dry Fuel	1.63	0.0857

II. DESCRIPTION OF THE EXPERIMENT

A. PCTR Test Lattice

The test cavity of the PCTR is 41.25" x 41.25" x 37.5" into which experimental lattices are placed. The test lattice was constructed of a 5x5 array of 7.5" square graphite cells with 18 fuel columns and 7 target columns. There are actually three different arrangements of fuel and target material which could have been used as a test cell array and which are depicted below:

At the start of the experiment, there seemed to be no apparent reason for preference of one type array over another, except that #1 was a little easier to construct in the test cavity. Therefore, the experiment was conducted with array #1 (Figure 1). Before the experimental measure-

U → 1.25% Enriched Uranium
 T → Thoria at 77% Theoretical Density
 7.50" Lattice Pitch

FIGURE 1
 (5x5 Test Cell Array) PCTR Core Fuel Loading Diagram

U = 1.25 wt% U^{235}

T = Thoria at 77% Theoretical Density

FIGURE 2
(6 x 6 Test Cell Array)
PCTR Core Fuel Loading Diagram

ments were concluded, however, the graphite cells were rearranged in the test cavity according to the type #3 array as depicted in Figure 2. The measured mass of copper for unit multiplication was remeasured in the lattice with coolant and the result was significantly different from the data received with the 5x5 test array.

The investigation of this difference was continued in another uranium fuel and target experiment⁽¹⁾ which followed and it was discovered that the 6x6 array of square shaped cells is the correct measurement technique. The correctness relies on the fact that the void formed by removal of the center supercell in the 6x6 array exposes six surfaces of fuel cells and two surfaces of target cells (precisely a 3-1 ratio). The 6x6 array is considered to be the more typical of an infinite array of 3-1 supercells and therefore all of the results for this experiment have been corrected in this document to be compatible with the results measured in the 6x6 test lattice.

B. Definition of a Supercell

The test cell configuration has been depicted in Figure 1 which illustrates an outline of four cells in the center of the PCTR test cell. These cells, henceforth, will be referred to as the center supercell which consists of three fuel columns and an adjacent target column. The critical measurements for the experiment were done using the inner or center section of the supercell.

The cells comprising the supercell can be further distinguished by their physical relation to the target cells. Two of the fuel columns per supercell are adjacent to one target column and will be called U_1 cells.

The remaining fuel cell per supercell is between two target columns and will be called a U_2 cell. Each supercell, then, is further defined as consisting of two U_1 cells and one U_2 cell, and one target cell.

The neutron absorption rates of these type cells were different so that in an experiment of this type the data was threefold. Each type cell has its own neutron characteristics and had to be measured and treated separately.

C. Fuel and Target Dimensions and Physical Constants

The fuel was 1.250 wt% enriched uranium and the target was thorium at 77% theoretical density. Both fuel and target material were clad in separate aluminum containers. The supercell was 21.875" long to allow for front and rear buffers of similar material in the 37.5" PCTR test cavity. Both fuel and target elements were encased in separate zirconium process tubes. Details of the center fuel cells are listed in Table III; center target cell details are listed in Table IV.

The thorium powder in the central supercell was compacted to 77.2% theoretical density (10.0 g/cc) and had a thorium-to-thorium weight ratio of 0.8778. The total uranium content in the thorium was 2 ppm.

The ^{235}U content in the fuel was 1.2559 wt% as determined by chemical analysis of samples from the central supercell elements, and the relative isotopic abundances were determined by mass spectrograph measurements of similar samples (see Table V).

TABLE III

Composition and Geometry of the Fuel Center Cell with Coolant

Region			Outer	Density	Center Cell
Name	No.	Isotope	Radius cm	gm/cm ³	Mass gms
Water	1		0.549	0.9955	52.5420
		H		0.1113	5.8795
		O		0.8842	46.6625
Clad	2	Al	0.625	2.6990	39.4269
Fuel	3		1.840	18.816	9837.9566
		²³⁵ U			123.5146
		²³⁸ U			9714.4420
Clad	4	Al	1.916	2.6690	134.858
Water	5		2.184	0.9955	191.8178
		H		0.1113	22.8282
		O		0.8842	168.9896
Process Tube	6	Zr	2.286	6.400	507.4090
Void	7		2.337	1.209x10 ⁻³	0.0527
		N		9.2554x10 ⁻⁴	0.0405
		O		2.8361x10 ⁻⁴	0.0122
Graphite	8		11.189 (a,b)		
		C		1.6714	30,943.506
		N		2.6543x10 ⁻⁴	4.6663
		O		8.1330x10 ⁻⁵	1.4089

(a) Cylindricized radius

(b) Cells 12 and 14 = 11.189 cm

Cell 18 = 11.674 cm

TABLE IV

Composition and Geometry of the Target Center Cell with Coolant

Region		Isotope	Outer Radius cm	Density gm/cm ³	Center Cell mass - gm.
Name	No.				
Target	1	Th	1.835	7.6119	4549.000
		O			3992.234
					555.766
Clad	2	Al	1.975	2.699	250.746
Water	3		2.184	0.9956	157.080
		H		0.1114	17.577
		O		0.8842	139.503
Process Tube	4	Zr	2.286	6.4000	507.409
Void	5		2.337	1.209×10^{-3}	0.05278
		N		9.2554×10^{-4}	0.04054
		O		2.8316×10^{-4}	0.01224
Graphite	6		8.682(a)		30,751.152
		C		1.6714	30,745.060
		N		2.6543×10^{-4}	4.67920
		O		8.1330×10^{-5}	1.41283

(a) Cylindricized radius

TABLE V

Isotopic Analysis Report of Fuel^(a)Sample 1:

<u>Mass</u>	<u>Atom %</u>	<u>Weight %</u>
238	98.7079 $\pm$ 29	98.7240 $\pm$ 29
236	0.0132 $\pm$ 8	0.0131 $\pm$ 8
235	1.2710 $\pm$ 29	1.2551 $\pm$ 29
234	0.0079 $\pm$ 3	0.0078 $\pm$ 3

Sample 2:

238	98.7063 $\pm$ 60	98.7223 $\pm$ 60
236	0.0130 $\pm$ 4	0.0129 $\pm$ 4
235	1.2725 $\pm$ 60	1.2567 $\pm$ 60
234	0.0082 $\pm$ 4	0.0081 $\pm$ 4

(a) C. R. Lagergren, 326 Building, 300 Area

III. EXPERIMENTAL TECHNIQUE

A. PCTR Method For Determination of k_{∞}

The experimental technique was not significantly different from standard PCTR experiments.^(3,4) Specifically, the poisoned lattice was flux matched to give a neutron energy distribution in the test cell that is typical of the distribution in an infinite array of such cells. Foils were activated in the central test cell to measure the relative absorption rates of the cell components.

Differential reactivity measurements were made to determine the worth of the central test cell, the sensitivity to the addition of copper on the boundary of the test cell and in the cavity created by the removal of the test cell. Results of these measurements yield a mass of copper (defined as M_0) which is required to poison the test cell to unit multiplication. Figure 3 shows the center test cell being removed from the 5x5 test array.

The relative reaction rates of the test cell components are measured in both the lattice poisoned to unit multiplication and the unpoisoned lattice when the proper neutron energy distribution exists in the test cell.

FIGURE 3

Central Supercell Loading in PCTR Core, 5x5 Test Cell Array

B. Flux Matching Analysis

The criteria of a matched neutron spectrum in the supercell test lattice that would be typical of an infinite array of such cells is not as easily defined as it would be for tests of homogeneous fuel. Therefore, the method developed for this experiment is described below.

Five-mil gold foils approximately 1/2" in diameter were irradiated bare and in 40-mil cadmium covers to obtain cadmium ratios from which flux match data could be determined. The foils were placed on a radius approximately 2.5" away from the center of both fuel and target materials so that reasonable changes in spectrum could be measured. Generally, the objective was to match all three cell types in the test lattice, (i.e., U_1 , U_2 , and thoria) so that each type would correspond to the center cell of the same type. In deciding on a flux match the following comparisons were made:

<u>Cell Type</u>	<u>Center Cell</u>	<u>Equivalent Radial Cells</u>
U_1	12 + 14	2, 4, 7, 9, 17, 19, 22, 24
U_2	18	1, 5, 8, 11, 15, 21, 25
Th	13	3, 6, 10, 16, 20, 23

Specifically, a weighted average of the cadmium ratio of the equivalent radial cells was computed for comparison with the cadmium ratio of the respective center cell. The weighting used was the inverse of the linear distance, center to center, from a radial cell to the nearest center cell of the same type. These weighted values are listed in Table VI.

TABLE VI

Radial Weighting Constants for Cadmium Ratio Flux Match						
Type	Cell	Linear Distance	# Equiv. Cells	1/L	N/L = Wi	$\sum Wi$
U ₁	7	7.5	4	.1333	.5332	
	24	15.0	4	.06667	.2668	.79988
U ₂	11	16.77	1	.05963	.05963	
	21	16.77	2	.05963	.11926	
	15	16.77	1	.05963	.05963	
	5	27.05	2	.03696	.07392	
	8	15.00	1	.06666	.06666	.3791
Th	3	15.0	2	.06667	.13334	
	16	16.77	4	.05963	.23852	.37186

Using the parameters in Table VI, the following quantities are defined:

$$\overline{CTR} = \frac{2\overline{U}_1 + \overline{U}_2 + \overline{Th}}{4}$$

where $\overline{U}_1$ = average CDR of U₁ type columns in center supercell.

$\overline{U}_2$ = average CDR of U₂ type columns in center supercell

$\overline{Th}$ = average CDR of Th type columns in center supercell.

$$\overline{RD} = \frac{2CDR_{U_1} + CDR_{U_2} + CDR_{Th}}{4}$$

$$\overline{CDR}_1 = \frac{\sum W_1 CDR_1}{\sum W_1} \quad \text{where } CDR_j \text{ is the cadmium ratio of each cell type.}$$

The specific criteria for flux match conditions, therefore, is defined by the equivalence of $\overline{CTR}$ and $\overline{RD}$, that is,

$$\overline{CTR} = \overline{RD}$$

when the drivers have been properly adjusted.

TABLE VII

Matched Supercell Average Gold Cadmium Ratios

Flux Match Attempt #	Cell Condition	Average Cadmium Ratio		M_o (1/v) gm/Cu (5x5 test lattice)
		Center Cells	Radial Cells (Weighted)	
1	Wet-Poisoned	4.889	4.550	704.96
2	Wet-Poisoned	5.096	4.799	700.25
3	Wet-Poisoned	5.220	5.275	712.26
4	Wet-Poisoned	5.217	5.281	710.62
1	Dry-Poisoned	3.988	3.864	972.25
2	Dry-Poisoned	3.843	3.645	1009.76
3	Dry-Poisoned	3.908	3.975	1017.81
4	Dry-Poisoned	3.867	3.911	1021.75
5	Dry-Poisoned	3.882	3.946	1023.30

C. Determination of Poison Requirements

Standard PCTR techniques are to measure the absorber requirements necessary to achieve unit multiplication after every change in the neutron spectrum. A detailed description of this technique can be found in references (3,4) and which has been simplified to the equation below:

$$M_o = \frac{\rho^{\text{cell in}} - \rho^{\text{cell out}}}{\text{Units of reactivity per gram of absorber}} + M$$

where: M = mass of copper on the cell boundaries;

$\rho^{\text{cell in}}$ = pile reactivity with cell in;

$\rho^{\text{cell out}}$ = pile reactivity with cell out, corrected to exclude nitrogen effects.

It can be seen readily that the reactivity worth of the cell and of the poison will change as the neutron spectrum changes. Because it is impractical to achieve an exact flux match as well as a unit multiplication factor, several measurements are usually made which bracket the desired flux

match, and the poison requirements for each case are determined. The correct poison requirements may be derived by analytical extrapolation from this data.

The analytical method defined for this experiment was to determine a straight line function of the average radial cadmium ratios ($\overline{RD}$) with respect to the cadmium ratio of the center cell, ($\overline{CTR}$). Likewise, a straight line function of the necessary mass of copper to achieve unit multiplication (M_o) with respect to the cadmium ratio of the center cell ($\overline{CTR}$) was also calculated. The exact poison requirements could be determined from these two functions. The graphic results of this method are shown in Figures 4 and 5 for the dry case, Figures 6 and 7 for the lattice experiment with coolant.

FIGURE 4
Gold Cadmium Ratio Analysis 3-1 Uranium-Thoria Supercell
Dry Poison Case

FIGURE 5
Mass of Copper Analysis 3-1 Uranium-Thoria Supercell
Dry Poison Case

FIGURE 6
Gold Cadmium Ratio Analysis 3-1 Uranium-Thoria Supercell
Wet Poison Case

FIGURE 7
Mass of Copper Analysis 3-1 Uranium-Thoria Supercell
Wet Poison Case

D. Relative Reaction Rate Measurements

Relative reaction rates of the test cell components are determined from foil activation measurements. The energy dependence of these reaction rates are determined from cadmium ratios. Specifically, .010" thick copper foils were activated in two separate irradiations, one with bare foil and the other with foils containing .040" thick cadmium covers. The irradiation data was normalized by placing monitor foils in an external thermal column⁽⁵⁾ and corrected for mass and counting time differences using a computer code APDAC.⁽⁶⁾ These irradiations are taken after the proper neutron spectrum matching has been indicated by the gold foil cadmium ratio data.

The location of the foils in the center supercell during the irradiations requires strategic placement so that accurate reaction rates can be determined. Figure 8 illustrates the foil locations used for this experiment.

Figure 9 shows a target cell and a fuel clad from the central supercell with the special separable elements and other provisions for foil traverses. Special sector and quadrant foils were made to integrate the neutron reaction rate over the area of the fuel and target, respectively. In order to obtain spatial detail of the reaction rate integrals, a copper sector foil irradiated in the fuel and a copper quadrant irradiated in the target were dissected into several radial regions after irradiation and counted separately.

FIGURE 9

Separable Elements and Provisions for Foil Measurements

Because there were no end caps included in the center cell fuel and target material, and because it is possible to adjust the front and rear level rings to control the axial flux pattern, the axial flux distribution was near flat within the measured accuracy. Therefore, the distribution is not printed here.

The specific activities of the copper foils placed in the graphite relative to the normalizing foil in the external thermal column are listed in Table 8 for the lattice with coolant and in Table 9 for the lattice without coolant.

The copper and gold foil relative activities are calculated using a revised version of the computer code APDAC-I,⁽⁶⁾ which corrects the counting data for activity decay between counts, room background, foil mass variations, and residual activity. Representative graphs of the total and episcadmium fluxes relative to the copper-63 activity variation along the angular traverse direction between an adjacent fuel and target cell are shown in Figures 10 and 11.

TABLE VIII

Relative Activities of Copper Foils in Central Supercell Graphite
(With Coolant)

Traverse Position	Poisoned			Unpoisoned		
	Radius Activity			Radius Activity		
	Inches	Bare	Cadmium Cov.	Inches	Bare	Cadmium Cov.
Ref.*		1.000	1.000	Ref.*	1.000	1.000
r ₁	3.750	2.826	.208	3.750	3.887	.161
r ₂	2.420	2.700	.206	2.420	2.756	.159
r ₃	1.000	1.963	.197	1.000	2.033	.159
r ₄	1.000	2.012	.196	1.000	2.035	.153
r ₅	2.420	2.867	.203	2.420	2.919	.160
r ₆	3.750	3.110	.206	3.750	3.191	.161
r ₇	2.420	3.12	.203	2.420	3.180	.161
r ₈	1.000	2.718	.194	1.000	2.758	.151
r ₉	1.170	2.806	.198	1.170	2.880	.153
r ₁₀	1.670	2.990		1.670	3.160	
r ₁₁	2.170	3.079	.201	2.170	3.160	.158
r ₁₂	2.670	3.148		2.670	3.218	
r ₁₃	3.170	3.178	.202	3.170	3.242	.160
r ₁₄	3.670	3.160	.206	3.670	3.165	
r ₁₅	3.670	3.089		3.670		
r ₁₆	3.120	3.041	.204	3.170	3.068	.155
r ₁₇	2.670	2.914		2.670	2.967	
r ₁₈	2.170	2.759	.201	2.170	2.810	.156
r ₁₉	1.670	2.540		1.670	2.628	
r ₂₀	1.170	2.217	.193	1.170	2.265	.151
r ₂₁	1.170	2.790	.194	1.170	2.854	.153
r ₂₂	1.670	2.973		1.670	3.030	
r ₂₃	2.170	3.070		2.170	3.143	
r ₂₄	2.670	3.123	.201	2.670	3.202	.157
r ₂₅	3.170	3.161		3.170	3.205	
r ₂₆	3.670	3.148		3.670	3.203	
r ₂₇	4.170	3.171	.203	4.170	3.199	.159
r ₂₈	4.170	3.084	.204	4.170	3.085	.156
r ₂₉	3.670	3.055		3.670	3.046	
r ₃₀	3.170	2.978		3.170	3.001	
r ₃₁	2.670	2.881	.201	2.670	2.693	.158
r ₃₂	2.170	2.741		2.170	2.767	
r ₃₃	1.670	2.543		1.670	2.570	
r ₃₄	1.170	2.213	.189	1.170	2.238	.150
r ₃₅	1.170	2.190	.190	1.170	2.188	.147
r ₃₆	1.670	2.497		1.670	2.539	
r ₃₇	2.170	2.695		2.170	2.760	
r ₃₈	2.670	2.822	.196	2.670	2.883	.155
r ₃₉	3.170	2.902		3.170	2.992	
r ₄₀	3.670	2.969		3.670	2.026	
r ₄₁	4.170	3.008	.200	4.170	3.073	.156

* External Thermal Column

TABLE IX

28

Relative Activities of Copper Foils in Central Supercell Graphite
(Without Coolant)

Traverse Position	Poisoned			Unpoisoned		
	Radius	Activity		Radius	Activity	
	Inches	Bare	Cadmium Cov.	Inches	Bare	Cadmium Cov.
Ref.*		1.000	1.000	Ref.*	1.000	1.000
r ₁	3.750	2.511	.135	3.750	3.673	.142
r ₂	2.420	2.425	.134	3.420	2.588	.141
r ₃	1.000	1.946	.128	1.000	2.088	.132
r ₄	1.000	1.961	.128	1.000	2.164	.136
r ₅	2.420	2.478	.135	2.420	2.706	.141
r ₆	3.750	2.635	.128	3.750	2.883	.142
r ₇	2.420	2.627	.131	2.420	2.865	.139
r ₈	1.000	2.387	.122	1.000	2.583	.120
r ₉	1.170	2.454	.124	1.170	2.707	.132
r ₁₀	1.670			1.670	2.706	.134
r ₁₁	2.170	2.620	.120	2.170	2.878	.137
r ₁₂	2.670	2.657		2.670	2.919	.139
r ₁₃	3.170	2.677	.132	3.170	2.934	.141
r ₁₄	3.670	2.670		3.670	2.947	.140
r ₁₅	3.670	2.626	.135	3.670	2.579	
r ₁₆	3.170	2.585	.134	3.170	2.828	.142
r ₁₇	2.670	2.519		2.670	2.706	
r ₁₈	2.170	2.420	.132	2.170	2.661	.140
r ₁₉	1.670	2.304		1.670	2.519	
r ₂₀	1.170	2.109	.128	1.170	2.299	.136
r ₂₁	1.170	2.405	.125	1.170	2.635	.131
r ₂₂	1.670	2.507		1.670	2.764	
r ₂₃	2.170	2.576		2.170	2.833	
r ₂₄	2.670	2.619	.120	2.670	2.715	.138
r ₂₅	3.170	2.643		3.170	2.900	
r ₂₆	3.670	2.647		3.670	2.897	
r ₂₇	4.170	2.639	.132	4.170	2.910	.142
r ₂₈	4.170	2.576	.132	4.170	2.861	.143
r ₂₉	3.670			3.670	2.831	
r ₃₀	3.170	2.521		3.170	2.766	
r ₃₁	2.670	2.464	.131	2.670	2.694	.141
r ₃₂	2.170	2.399	.124	2.170	2.715	
r ₃₃	1.670	2.269		1.670	2.482	
r ₃₄	1.170	2.076	.124	1.170	2.270	.125
r ₃₅	1.170	2.066	.121	1.170	2.234	.134
r ₃₆	1.670	2.259	.123	1.670	2.440	.134
r ₃₇	2.170	2.410	.125	2.170	2.577	.136
r ₃₈	2.670	2.478	.127	2.670	2.678	.141
r ₃₉	3.170	2.535		3.170	2.742	
r ₄₀	3.670	2.582		3.670	2.779	
r ₄₁	4.170	2.614	.126	4.170	2.801	.143

* External thermal column

FIGURE 10
Cylindricized Radial Traverse Between Target and Fuel in
the Lattice With Coolant

FIGURE 11
Cylindricized Radial Traverse Between Target and Fuel in
the Lattice Without Coolant

The measured spatial distribution of the relative reaction rates in copper-63, $SA^{63}(r)$, which were discussed and illustrated alone, were corrected for non- $1/v$ absorption rates. These corrections are inferred from copper-63 cadmium ratio measurements and resonance integral data,⁽⁷⁾

$$SA^{63}_{1/v}(r) = SA^{63}_{Total}(r) - SA^{63}_{epi-Cd}(r) \frac{RI_{ex}}{RI_{epi-Cd}}$$

where RI_{ex} = effective resonance integral for copper-63 in a 0.010" thick foil, 1.63073 barns;

RI_{epi-Cd} = effective total epi-cadmium resonance integral for copper-63 in a 0.010" thick foil, 3.42011 barns.

E. Neutron Cross Sections and THERMOS Cell Calculations

The SA^{63} foil activities in the moderator served two purposes; to determine the relative reaction rates of the cell components and to determine the cell boundary conditions which were, in turn, used in transport theory calculations for the generation of spectrum averaged cross sections.

Specifically, two dimensional plots were made of the sub-cadmium neutron reaction rates in copper-63. By taking sufficient traverses the sub-cadmium zero net current boundary between adjacent cells could be determined. These plots are shown in Figures 12 and 13 for the lattice with and without coolant, respectively. The equivalent cylindrical cell radii are tabulated in these figures.

Equivalent Cell Radii			
Cell Type	Area, in ²	Radius, in	Radius cm
Target	36.703	3.418	8.682
U ₁	60.959	4.405	11.189
U ₂	66.360	4.596	11.674
Physical Boundary	56.25	4.231	10.747

FIGURE 12 Subcadmium Iso-Flux Lines in Wet Uranium-Thoria Supercell (1.449 in. OD fuel)

FIGURE 13 Subcadmium Iso-Flux Lines in Dry Uranium-Thoria Supercell (1.449 in. OD fuel)

Thermal neutron spectrum averaged microscopic cross section values, calculated by transport theory methods, were obtained from computer code THERMOS.⁽⁸⁾ Each cell received an individual calculation for both the wet and dry case with reflecting geometry and outer boundary determined from the equivalent cell radius, previously derived via the experimental data.

The calculated THERMOS cross sections are defined as:

$$\hat{\sigma}(r) = \frac{\int_0^{E_{ec}} \sigma(E) \phi(E, r) dE}{\int_0^{E_{ec}} \sqrt{E_0/E} \phi(E, r) dE}$$

where, $E_{ec} = 0.683$ ev;

$E_0 = 0.0253$ ev;

$\phi(E, r)$ = space energy dependent neutron flux.

The region averaged cross sections determined by the method described above are listed in Table X and XI. Most of the cross sections listed are the 2200 m/sec values except when the cross section is non-1/v for $0 \leq E \leq 0.683$.

TABLE X

Thermal Average Cross Sections from THERMOS

Isotope	<u>U₁-Type Fuel Cell, Lattice With Coolant</u>		
	$\bar{\sigma}_a$	$\bar{\sigma}_a^{(a)} 1/v$	$\hat{\sigma}_i = \frac{(\bar{\sigma}_a)_i}{(\bar{\sigma}_a 1/v)_i}$
H	0.2262	0.68143	0.38513
O	1.4309×10^{-4}	0.68143	2.0998×10^{-4}
Al	0.5673	0.68143	0.2300
²³⁵ U	409.745	0.63839	641.841
²³⁸ U	1.7672	0.73274	2.7682
Al	0.1685	0.73274	0.2300
H	0.2433	0.73274	0.3320
O	1.5384×10^{-4}	0.73274	2.0998×10^{-4}
Zr	0.1389	0.73274	0.1800
N	1.2823	0.73274	1.7500
O	1.5386×10^{-4}	0.73274	2.0998×10^{-4}
C	2.5316×10^{-3}	0.74459	3.4000×10^{-3}
N	1.3031	0.74459	1.7500
O	1.5635×10^{-4}	0.74459	2.0998×10^{-4}
Cu	2.8075	0.74077	3.7900

Isotope	<u>U₂-Type Fuel Cell, Lattice With Coolant</u>		
	$\bar{\sigma}_a$	$\bar{\sigma}_a^{(a)} 1/v$	$\hat{\sigma}_i = \frac{(\bar{\sigma}_a)_i}{(\bar{\sigma}_a 1/v)_i}$
H	0.2274	0.6848	0.3320
O	1.4379×10^{-4}	0.6848	2.0998×10^{-4}
Al	0.1575	0.6848	0.2300
²³⁵ U	421.673	0.6425	642.330
²³⁸ U	1.7781	0.6425	2.768
Al	0.1696	0.7375	0.2300
H	0.2448	0.7375	0.3320
O	1.5485×10^{-4}	0.7375	2.0998×10^{-4}
Zr	0.1327	0.7375	0.1800
N	1.2906	0.7375	1.7500
O	1.5485×10^{-4}	0.7375	2.0998×10^{-4}
C	2.5528×10^{-3}	0.7508	3.40×10^{-3}
N	1.3140	0.7508	1.7500
O	1.5766×10^{-4}	0.7508	2.0998×10^{-4}
Cu	2.8290	0.7483	3.79

(a) $\sigma_{a_0} = 1.000$

TABLE XI

Thermal Average Cross Section for Thermos

Isotope	<u>Thoria Target Cell</u>		$\hat{\sigma}_i = \frac{(\bar{\sigma})_i}{(\bar{\sigma}_{a,u})_i}$
	$\bar{\sigma}_a$	$\bar{\sigma}_{a_{1/v}} (a)$	
Th	5.4699	.7235	7.55950
O	1.5194×10^{-4}	.7235	0.00020
Al	0.1752	.7616	0.23000
H	0.2513	.7662	0.33200
O	1.6089×10^{-4}	.7662	0.00021
Zr	0.1379	.7662	0.18000
N	1.3448	.7684	1.75000
O	1.6136×10^{-4}	.7684	0.00021
C	2.6127×10^{-3}	.7684	0.00335
N	1.3448	.7684	1.75000
O	1.6136×10^{-4}	.7684	0.00021

F. 1/v Utilization

The 1/v utilization of a cell component is defined as the ratio of the 1/v absorption rate in that component, to the sum of 1/v absorption rates in all cell components. The experimental values of this parameter are derived from the calculated cross section data and the experimentally measured 1/v neutron reaction rate in Cu-63. At space point r the 1/v absorption rate in Cu-63 is given by:

$$\overline{SA}^{63}(r) = c \frac{N_o}{A^{63}} \hat{\sigma}^{63}(r) \int_0^{c o \sqrt{E_o/E}} \phi(E, r) dE ,$$

where c is a space independent normalizing constant. A similar value of $\overline{SA}^x$ for the material, x , in any given region, may be obtained from the simple ratio,

$$\overline{SA}^x(r) = \frac{\hat{\sigma}^x(r) A^{63}}{\hat{\sigma}^{63}(r) A^x} \overline{SA}^{63}(r)$$

where A is the atomic weight.

The total 1/v absorption rate in material x , $(Abs)^x$, may be obtained for a region by the volume weighted average of $\overline{SA}^x(r)$:

$$(Abs)^x = M^x \frac{\int_1 \overline{SA}^x(r) dv}{\int dv} = (\Sigma a \phi V);$$

Both integrals are integrated over all of x and M is the mass of material x in the region.

Finally, then, as stated previously,

$$f = \frac{(\sum_a \phi V)_{\text{fuel}}}{\sum (\sum_a \phi V)_i + (\sum_a \phi V)_{\text{fuel}}}$$

$$f' = \frac{(\sum_a \phi V)_{\text{fuel}}}{\sum (\sum_a \phi V)_i + \sum_a \phi V_{\text{fuel}} + \sum_a \phi V_{\text{poison}}}$$

TABLE XII

Experimental 1/v Absorption Rates and k_{∞} MeasurementsI. Lattice With Coolant:

#	Region	Isotope	Abs 1/v Non-Poison Case	Abs 1/v Poison Case
1	Target	Th	3684.926	3379.859
		O	0.207	0.190
2	Clad	Al	64.574	59.859
3	Water	H	181.057	170.398
		O	0.057	0.053
4	Process Tube	Zr	33.402	31.408
5	Air	O	0.000	0.001
		N	0.178	0.166
6	Moderator	C	343.696	307.997
		N	23.086	20.691
		O	0.001	0.001
	TOTAL TARGET CELL:		4331.184	3970.622
1	Water	H	30.622	30.200
		O	0.014	0.009
2	Clad	Al	4.868	4.618
3	Fuel	^{235}U	4887.646	4539.746
		^{238}U	1630.413	1520.489
4	Clad	Al	18.536	18.443
5	Water	H	152.701	144.079
		O	0.045	0.042
6	Process Tube	Zr	24.465	22.748
7	Air	N	0.145	0.000
		O	0.000	0.133
8	Moderator	C	322.584	295.098
		N	21.530	19.640
		O	0.001	0.001
	TOTAL U_1 FUEL CELL:		7093.567	6599.390

TABLE XII

<u>#</u>	<u>Region</u>	<u>Isotope</u>	<u>Abs 1/v Non-Poison Case</u>	<u>Abs 1/v Poison Case</u>
1	Water	H	30.622	29.608
		O	0.014	0.009
2	Clad	Al	4.822	4.618
3	Fuel	²³⁵ U	4861.461	4545.283
		²³⁸ U	1618.086	1521.079
4	Clad	Al	19.217	18.443
5	Water	H	153.040	144.079
		O	0.045	0.042
6	Process Tube	Zr	24.465	22.748
7	Air	N	0.044	0.040
		O	0.000	0.000
8	Moderator	C	322.857	294.692
		N	21.686	19.794
		O	0.000	0.000
TOTAL U ₂ FUEL CELL:			7056.358	6600.437

Copper poison (5x5) 1472.689

 (6x6) 1597.546

TOTAL SUPERCELL f 1/v = 0.76324 } (5x5)
 (Air atmosphere) f' 1/v = 0.72060 }

f' 1/v = 0.71708 (6x6)

TABLE XIII

Experimental 1/v Absorption Rates and k_{∞} Measurement
(Fuel Cells Without Coolant)

II. Lattice Without Coolant:

#	Region	Isotope	Abs 1/v Non-Poison Case	Abs 1/v Poison Case
1	Target	Th	4186.376	3117.124
		O	0.235	0.175
2	Clad	Al	74.269	55.492
3	Air	N	0.666	0.503
		O	0.000	0.000
4	Process Tube	Zr	35.809	27.000
5	Air	N	0.183	0.138
		O	0.000	0.000
6	Moderator	C	363.507	271.205
		N	24.418	15.954
		O	0.000	0.000
	TOTAL TARGET CELL:		4685.462	3487.670
1	Air	N	0.057	0.044
		O	0.000	0.000
2	Clad	Al	5.030	3.877
3	Fuel	²³⁵ U	5772.690	4412.643
		²³⁸ U	1947.680	1494.185
4	Clad	Al	26.407	20.573
5	Air	N	0.347	0.258
		O	0.000	0.000
6	Process Tube	Zr	25.514	18.987
7	Air	N	0.133	0.099
		O	0.000	0.000
8	Moderator	C	341.287	251.187
		N	22.684	16.718
		O	0.001	0.000
	TOTAL U ₁ FUEL CELL:		8141.828	6218.571

TABLE XIV

Experimental $1/v$ Absorption Rates and k_{∞} Measurement
 (Target Cell Without Coolant)

#	Region	Isotope	Abs $1/v$ Non-Poison Case	Abs $1/v$ Poison Case
1	Air	N	0.057	0.045
		O	0.000	0.000
2	Clad	Al	5.030	3.900
3	Fuel	^{235}U	5710.967	4396.112
		^{238}U	1926.860	1487.213
4	Clad	Al	26.541	20.573
5	Air	N	0.347	0.258
		O	0.000	0.000
6	Process Tube	Zr	25.514	18.987
7	Air	N	0.040	0.029
		O	0.000	0.000
8	Moderator	C	340.818	250.841
		N	20.043	16.849
		O	0.001	0.001
TOTAL U_2 FUEL CELL:			8056.217	6194.809

Copper poison (5x5) 1711.327
 (6x6) 2047.185

TOTAL SUPERCELL: $f \ 1/v = 0.79526$ }
 (Air atmosphere) $f' \ 1/v = 0.74282$ } (5x5)

$f' \ 1/v = 0.73250$ (6x6)

G. Determination of k_{∞}

The equation for calculating k_{∞} in this system for which the thermal absorption cross sections are nearly $1/v$, is derived from the four factor formula,⁽⁹⁾

$$k_{\infty} = \eta \epsilon p f . \quad (1)$$

It is assumed that the addition of copper to the boundary of the supercell will change only the thermal utilization, hence the multiplication factor, (k_{∞}') of the supercell with the correct mass of copper (M_0) is unity;

$$k_{\infty}' = \eta \epsilon p f' = 1 \quad (2)$$

Thus, k_{∞} has been derived (2) as the ratio of the unpoisoned to poisoned thermal utilizations of the supercell;

$$k_{\infty} = \frac{f}{f'} , \text{ where} \quad (3)$$

f = the $1/v$ utilization of the unpoisoned supercell,

f' = the $1/v$ utilization of the poisoned supercell.

The derivation of the f $1/v$ (in equation 3) is based on the assumption that the absorption rates in all the cell components, except for the resonance absorptions in ^{238}U , can be calculated by using the flux measured by a detector whose absorption cross section varies as $1/\sqrt{E}$ multiplied by the 2200 m/sec cross sections calculated by THERMOS. The use of the four factor formula in the derivation of $k_{\infty} 1/v$ implies that,

$$k_{\infty} 1/v = n_{1/v} \epsilon P_{nm_{1/v}} f_{1/v} \quad (4)$$

Therefore, all non- $1/v$ epithermal absorption is accounted for in the resonance escape probability, $P_{\text{non-}1/v}$.

Equation 3 can be rewritten in terms of absorption rate as stated previously;

$$k_{\infty}-1 = \frac{(Abs)_p}{\sum_i (Abs)_i} + \sum_i \frac{[(Abs)_{i'} - (Abs)_i]}{\sum_i (Abs)_i} \quad (5)$$

$(Abs)_p$ = relative $1/v$ absorption rate in the copper poison;

$(Abs)_{i'}$ = relative $1/v$ absorption rate in i th component of the supercell with poison (Cu).

$(Abs)_i$ = relative $1/v$ absorption rate in the i th component of the supercell without poison (Cu).

A condition on equation 5 is that the absorption rates in the fuel for the poison and unpoisoned cases are normalized to be equal.

Values for k_{∞} determined from this PCTR experiment are presented in Table I of the summary. The only differences are the geometry of the cavity used in the two measurements and formed by the removal of the supercell. Figures 14 and 15 illustrate these test lattices.

Figure 14

Test Lattice Loaded into the PCTR Cavity (5x5 Array)

Figure 15

Test Lattice Loaded into the PCTR Cavity (6x6 Array)

V. CORRECTIONS AND SYSTEMATIC ERRORS

A. Nitrogen Correction

When the supercell is removed nitrogen in air occupies the void spaces in the graphite and acts as a neutron absorber. The element is also expected to be in the void spaces of the lattice throughout the experiment. Therefore, the k_{∞} is calculated for a vacuum atmosphere by subtracting the neutron absorptions due to the nitrogen.

The reactivity effect of the nitrogen ($\Delta\rho_N$) which fills the center cell void cavity by removal of the center cell can be derived from a copper sensitivity measurement (δ_{Cu}^{cavity}) and the equation,

$$\Delta\rho_N = DC \frac{P}{T} (M_N)(1-c) \delta_{Cu}^{cavity} \quad (6)$$

where, D = thermal disadvantage factor for the thickness of copper

used in the measurement of $\delta_{Cu} = 1.0110''$

$$\delta_{Cu}^{cavity} = \Delta\rho_{Cu}^{cavity} / M_{Cu}^{cavity}, \text{ \textcent gram of copper} \quad (7)$$

$\Delta\rho_{Cu}^{cavity}$ = reactivity worth of mass of copper inserted into the center cell cavity to obtain δ_{Cu}^{cavity}

P = atmosphere pressure during the reactivity measurement, mb;

T = ambient temperature in PCTR during reactivity measurement, $^{\circ}K$;

M_N = mass of nitrogen at standard atmosphere pressure in the

cavity = 79.158 grams

$$c = \frac{\sigma_o^N A^{Cu} T_o}{\sigma_o^{Cu} A^N P_o} \quad (8)$$

σ_o^N = 2200 m/sec microscopic absorption cross section of nitrogen = 1.88 barns

$\sigma_o^{Cu} = 2200$ m/sec microscopic absorption cross section of
natural copper = 3.79 barns

A^{Cu}, A^U = copper and nitrogen atomic weights

T_o, P_o = standard temperature and pressure

The quantity (1-c) is a correction for the non-1/v nature of the
epithermal energy dependance of the absorption cross section of natural
copper, approximated by:

$$1-c = 1 - \left(\frac{m_1}{m_2} \right) \frac{RI_{ex}^{Cu}}{RI_{epi\ Cd}^{Cu} \text{ (CDR-1)}} \quad (9)$$

where, $\frac{m_1}{m_2}$ = ratio of the fast to thermal adjoint fluxes and is approximately
equal to the resonance escape probability = 0.8807, calculated
by MOFDA⁽¹⁰⁾

RI_{ex}^{Cu} = effective excess resonance integral of natural copper for
the thickness of copper used in measuring $\delta_{Cu}^{cavity} = 1.3705$
barns

RI_{epi-Cd}^{Cu} = effective epi-cadmium resonance integral of natural copper
for the thickness of copper used in measuring $\delta_{Cu}^{cavity} =$
2.8805 barns

B. 1/v Mass Equivalent for M_o ⁽¹¹⁾

Because the material used as the neutron absorber in the determination
of $k_{\infty} 1/v$ must have an effective cross section that varies at 1/E, it is
necessary to calculate the 1/v mass of copper ($M_{1/v}$), which will have a
reactivity coefficient equivalent to that measured by M_o .

$$M_{1/v} SA_{1/v} m_2 = M_o (SA_{1/v} m_2 + SA_{res} m_1) \quad (10)$$

Account is taken of the worth of epi-thermal resonance absorptions in copper relative to the worth of 1/v absorptions as follows:

$$M_{1/v} = M_o \left[1 + \frac{m_1}{m_2} \frac{RI_{ex}^{Cu}}{CdR \quad RI_{epi-Cd}^{Cu} - RI_{ex}} \right] \quad (11)$$

C. Central Cell End Effects

When the central supercell is removed from the test lattice in the course of the null reactivity measurements, the front and rear end buffers have one end of their process tubes exposed to the cell-out cavity. In some cases, with significantly black targets, this end exposure was known to effect the reactivity measurements. In this experiment, the target was such that the average reactivity change per length of center cell removed was not significantly different.

For clarification to the reader, there were not two different lengths of center cell manufactured for this experiment, but rather a front buffer piece and center cell piece were switched around for one set of reactivity series measurements, thus providing a shorter cell measurement to be used in the cell-out cases.

IV. EXPERIMENT WITH REDUCED DIAMETER FUEL AND RESULTS

A. Introduction

After completion of the earlier experiment it was determined to measure the change in the infinite medium neutron multiplication factors due to a reduction in fuel radial size and adding the area differences to coolant area.

B. Experimental Technique

This experiment was planned and carried out as an addendum to the earlier experiment. Therefore, the only fuel geometry changes were in the center cell fuel. There were no alterations to the target cell nor to the PCTR radial and front-to-rear buffer cells. The experimental procedure for these measurements were planned to permit as much use as possible of the data from the earlier experiment. Therefore, the following general methods were carried out:

1. Flux match via gold cadmium ratio measurements;
2. Measure mass of copper necessary to achieve unit multiplication in center cell;
3. Due to scheduling conflicts with the PCTR, relative SA_{Cu}^{63} activities necessary for determination of relative region absorptions were made only for the wet-poison experiment;
4. The SA^{63} activities for the dry-poison case, dry non-poison case, and wet non-poison case were generated using THERMOS and normalized to the wet-poison case, SA_{Cu}^{63} activities which were measured earlier.

There was also insufficient time to manufacture proper size aluminum cladding to contain the foil holders and separable elements necessary to the copper foil irradiations. Therefore, a second correction was calculated via THERMOS in order to derive SA_{Cu}^{63} activities which were applicable to the reactivity measurements which had the correct fuel cladding geometry.

C. Fuel Dimensions

The normal fuel dimensions as well as the fuel dimensions for the reduced diameter fuel are listed in Table XV. It should be noted that the equivalent radial cell dimensions remained constant for both experiments due to lack of information sufficient to derive a new set for the smaller fuel. However, the ratio of thermal absorption rates is not very sensitive to the effective boundary.

TABLE XV

Geometrical Comparison of Undersized Fuel and Normal Fuel Size

<u>Name</u>	<u>Region</u>		<u>Normal Fuel Radius (cm)</u>	<u>Undersized Fuel Radius (cm)</u>
	<u>Number</u>	<u>Isotope</u>		
Water	1	H O	0.549	0.549
Clad	2	Al	0.625	0.625
Fuel	3	^{235}U ^{238}U	1.840	1.770
Clad	4	Al	1.916	1.849
Water	5	N O		
Process Tube	6	Zr	2.286	2.286
Void	7		2.337	2.337
Graphite	8	N O C N O	11.189 (a,b)	11.189 (a,b)

(a) cylindricized radius

(b) 11.198 cells 12 and 14
11.674 cell 18

NOTE: The target material was not changed for these tests.

D. Null Reactivity Measured Results

The experimental measurements with the undersized fuel followed the general technique described in the earlier experiment. After the flux spectrum match comparison between buffer cells and radial cells was established using gold foil cadmium ratio analysis, the mass of copper (M_o) necessary to achieve unit multiplication in the center supercells was measured. The results of these reactivity measurements are listed in Table XVI with the similar type data previously listed for the normal size fuel.

TABLE XVI
Copper Absorber Requirements for Unit Multiplications
in 5x5 Test Lattice

<u>Cell Condition</u>	<u>M_o l/v</u>	
	<u>1.449" O.D. Fuel</u> <u>(grams)</u>	<u>1.392" O.D. Fuel</u> <u>(grams)</u>
Wet Fuel - Wet Target Wet Buffer	708.9	482.8
Dry Fuel - Dry Target Dry Buffer	1019.1	949.8

The relative gold foil cadmium ratio tests which define the degree of flux match between the center cell and the radial cells were especially important because only the center cell contained the undersized fuel. The results are as follows:

	<u>Average Cadmium Ratios</u>	
	<u>Wet</u>	<u>Dry</u>
$\bar{CTR}$ (center cell)	6.449	4.098
$\bar{RD}$ (radial cells)	6.368	4.064

The degree of reactivity change due to water loss in fuel and target, respectively, was measured in terms of the mass of copper necessary to achieve unit multiplication in the center test cell. The results are listed below in Table XVII.

TABLE XVII

Relative Effect of Separate Coolant Loss in
Target and Undersized Fuel

<u>Cell Condition</u>	<u>1.449" O.D. Fuel (M_O)</u>	<u>1.392" O.D. Fuel (M_O)</u>
Wet Target - Wet Fuel	1.00 (708.9 gm)	1.00 (482.8 gm)
Dry Target - Wet Fuel	1.07	1.13
Wet Target - Dry Fuel	1.56	2.02

E. Relative Absorption Rates

The relative reaction rates of the test cell components were determined from foil activation measurements as described in IV-B above.

The SA⁶³ activities necessary to determine the cell utilization for the wet non-poison case and the dry poison and non-poison cases were generated via THERMOS cell calculations. The factors were derived from the ratio of the 1/v relative activities normalized to the fuel and physical boundary of the U₁ cells and to the measured SA⁶³ activities previously determined for the wet-poison lattice.

TABLE XVIII

Theoretical and Experimental SA⁶³ Activities for Undersized Fuel Experiment

Region	LATTICE WITH COOLANT				LATTICE WITHOUT COOLANT			
	Poison		Unpoison		Poison		Unpoison	
	Cells 12&14	Cell 18	Cells 12&14	Cell 18	Cells 12&14	Cell 18	Cells 12&14	Cell 18
Water-Air	1.1245	1.4088	1.0873	1.0878	0.8263	0.8350	1.0769	1.0782
Aluminum	1.0182	1.2757	1.0034	0.9923	0.8392	0.8452	1.0894	1.0907
Fuel	0.9646	1.0112	1.0354	0.9956	0.9466	0.9426	1.2347	1.2220
Aluminum	1.0811	1.0928	1.0842	1.1843	1.2696	1.2728	1.2686	1.6372
Water-Air	1.4172	1.4325	1.4303	1.4312	1.2896	1.2929	1.7327	1.7336
Zirconium	1.7130	1.7253	1.7438	1.7459	1.3524	1.3530	1.8165	1.8175
Air	1.9812	1.9955	2.0436	2.0460	1.3915	1.3921	1.8731	1.8742
Moderator	2.5009	2.5009	2.5581	2.5581	1.9885	2.7634	2.6900	2.6992
Poison (Cu)	2.5756				1.9584			

F. 1/v Utilizations

The 1/v utilizations for the undersized fuel are listed in the following tables. These are calculated from the SA⁶³ activities listed in Table XVIII and THERMOS calculated cross sections.

The 1/v utilizations for the target cell with the undersized fuel are not significantly different from those measured with the normal size fuel so that they are not listed again in the following tables except for the total for the complete cell.

TABLE XIX

Experimental 1/v Absorption Rates and k_{∞} Measurements
Undersized Fuel (5x5 Lattice)

I. LATTICE WITH COOLANT:

#	Region	Isotope	Abs 1/v Non-Poison Case	Abs 1/v Poison Case
1	Water	H	29.074	29.967
		O	0.0	0.0
2	Clad	Al	2.617	2.645
3	Fuel	^{235}U	4359.176	4301.298
		^{238}U	1487.276	1361.706
4	Clad	Al	17.714	16.694
5	Water	H	171.010	169.092
		O	0.0	0.0
6	Process Tube	Zr	24.802	24.318
7	Air	N	0.149	0.140
		O	0.0	0.0
8	Moderator	C	352.223	343.841
		N	24.269	23.886
		O	0.0	0.0
	TOTAL U_1 FUEL CELL:		6468.510	6273.513
1	Water	H	28.914	37.081
		O	0.0	0.0
2	Clad	Al	2.587	3.277
3	Fuel	^{235}U	4393.298	4648.704
		^{238}U	1436.299	1453.233
4	Clad	Al	18.335	16.864
5	Water	H	171.171	170.857
		O	0.0	0.0
6	Process Tube	Zr	24.829	24.433
7	Air	N	0.150	0.14
		O	0.0	0.0
8	Moderator	C	377.482	367.886
		N	26.054	25.431
		O	0.6	0.0
	TOTAL U_2 FUEL CELL:		6479.1199	6749.921
	TOTAL TARGET CELL:		4143.280	4112.109
	TOTAL ABSORBER (Cu):			1035.416 (5x5)
	5x5 Lattice (Air Atmosphere) $f = 0.74382$			$f' = 0.71288$

TABLE XX

Experimental 1/v Absorption Rates and k_{∞} MeasurementsII. LATTICE WITHOUT COOLANT:

#	Region	Isotope	Abs 1/v Non-Poison Case	Abs 1/v Poison Case
1	Air	N	0.100	0.077
		O	0.0	0.0
2	Clad	Al	2.82	2.182
3	Fuel	^{235}U	5252.981	4010.764
		^{238}U	1778.659	1364.773
4	Clad	Al	25.217	19.654
5	Air	N	0.727	0.541
		O	0.0	0.0
6	Process Tube	Zr	25.840	19.239
7	Air	N	0.137	0.102
		O	0.0	0.0
8	Moderator	C	371.815	273.959
		N	25.827	19.276
		O	0.0	0.0
	TOTAL U_1 FUEL CELL:		7481.174	5710.920
1	Air	N	1.631	0.078
		O	0.0	0.0
2	Clad	Al	2.156	2.197
3	Fuel	^{235}U	5206.530	4026.175
		^{238}U	1759.082	1366.779
4	Clad	Al	25.3485	19.664
5	Air	N	0.727	0.541
		O	0.0	0.0
6	Process Tube	Zr	25.854	19.246
7	Air	N	0.137	0.102
		O	0.0	0.0
8	Moderator	C	397.855	407.212
		N	27.5026	28.149
		O	0.0	0.0
	TOTAL U_2 FUEL CELL:		7446.829	5870.156
	TOTAL TARGET CELL		4542.689	3334.935
	TOTAL ABSORBER (Cu)			1546.962 (5x5)
	5x5 Lattice (Air Atmosphere) $f = 0.78009$			$f' = 0.72805$

G. Infinite Medium Neutron Multiplication Factors

As stated previously, the infinite medium multiplication factors are derived from the ratio of the thermal utilizations (i.e., f/f'). However, it was also mentioned that the measurements in the 5x5 lattice array were in error due to an improper ratio of fuel and target faces exposed during cell-out reactivity measurements. In the earlier experiment with the normal size fuel the reactivity measurements were repeated with the 6x6 array of test cells. All the measurements with the undersized fuel, however, were made with the 5x5 array. Therefore, a corrected k_{∞} for the 6x6 array has been determined by multiplying the k_{∞} for the 5x5 array with the undersized fuel by the ratio of k_{∞} determined for the normal fuel size with the 5x5 and 6x6 array, respectively.

Ratio of k_{∞} for normal size fuel 6x6 array/5x5 array = 1.005 (with coolant);

Ratio of k_{∞} for normal size fuel 6x6 array/5x5 array = 1.014 (without coolant);

$$\frac{f}{f'} \text{ (with coolant)} = \frac{0.74382}{0.71288} = 1.0434 \times 1.005 = 1.0486;$$

$$\frac{f}{f'} \text{ (without coolant)} = \frac{0.78009}{0.72805} = 1.0734 \times 1.0141 = 1.0886.$$

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